LUBRICATION AND POWER CHARACTERISTICS
OF THE TEXTILE SPINDLE

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LUBRICATION AND POWER CHARACTERISTICS

OF THE TEXTILE SPINDLE

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SYMBOLS

d, diameter of torsion wire.

J, polar moment of inertia.

kw., kilowatt.

L, length of torsion wire.

n, speed of electric motor in revolutions per minute.

N, speed of spindle in revolutions per minute.

rpm, revolutions per minute.

Secs. S.U.V., seconds Saybolt Universal Viscosity and designation of oil based on 100° F.

ϕ, torque in radians twist of torsion wire.

θ_G, torque in degrees twist of torsion wire to drive belt, tension pulley, and spindle.

θ_T, torque in degrees twist of torsion wire to drive belt and tension pulley.

θ_{net}, $\theta_G - \theta_T$, torque in degrees twist of torsion wire to drive spindle.

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INTRODUCTION

Review of the Literature:

For the production of textiles, power is one of the most important items bearing on the cost of manufacture. Since the textile industry employs a wide variety of machinery, it lends itself to wasteful consumption and improper usage of power. The individual machine, or parts thereof, may use comparatively little power; but when several thousand machines are operating continuously, the amount can soon reach considerable proportions. In 1930 the textile industry was, from the viewpoint of power consumption, the second largest in the United States and probably is still near that position today.

Power consumption is greatly influenced by the extent of the friction in the various machines; and as the reduction of friction is the primary function of a lubricant, there is a close correlation between the power consumed by the textile industry and lubrication.

The spinning rooms of most mills use about 60 per cent of the total power consumed and the spindle itself uses the greatest portion of this; therefore, the greatest efforts towards improvement should start here. The lubrication of spindles to prevent wear has long been successful; but greater reduction in power consumed should be possible with improved lubrication.

Not many years ago the chief lubricant for all machinery was some type of vegetable or animal oil. It is interesting to note that the textile industry is on record as using a mineral oil as a lubricant some twenty years before the actual commercial production of petroleum. Mention is made by J. H. Bone of this fact in his book, "Petroleum and Petroleum Wells." He states that (27),

> "In the year 1845, Mr. Lewis Peterson, Sr. of Tarentum, Allegheny County, Pennsylvania brought to the Hope Cotton Factory at Pittsburgh a sample in a bottle of what is now known as petroleum. It came up with salt water from a salt well at Tarentum and gave him considerable trouble.... The manager of the spinning department, Mr. David Anderson, experimented with the oil and soon found that by a certain process it could be combined with sperm oil in such a way to form a better lubricator for the finest cotton spindles than the best sperm oil, which alone could be used for that purpose. The mixture cost about twenty cents a gallon, whilst the sperm oil alone cost one dollar and thirty cents. The savings was so great in one of the heavy items of expense in a large cotton factory, that a contract was entered into with Mr. Peterson by which the latter was to supply two barrels per week. And for ten years this oil continued to be used at the Hope Cotton Factory, unknown to any but the proprietors."

The production of the proper lubricant for a particular problem has reached a high degree of perfection due to the efforts of the leading oil companies. The education of the consumer to properly apply these lubricants has often fallen short, and this is a problem the textile industry faces. Too often management of mills has taken the attitude that "oil is just oil", and price alone has been the criterion for the lubricant purchased. The result has been machinery failure or increased production cost by high power consumption.

With the present trends to use high speed spinning, the necessity of choosing the correct lubricant has become very important. Originally the criterion for designation of a lubricant was on the basis of viscosity alone, but it was soon found that the lubricant must serve several other functions as well as possess certain chemical characteristics to be a good spindle lubricant.

Chemically, the lubricant must not be affected by oxidation. The result of oxidation in petroleum oils is to produce a rancid odor, a darkening in color, and a change in texture producing a gummy varnish-like deposit which is often sticky. Acidity is also developed which has corrosive effects on the highly polished surfaces of the spindle bearing. All of these are detrimental to power economy, the spindle life, or in the case of darkening oil, to the actual finished product.

Another desirable chemical characteristic of the spindle oil is that it can be removed readily from the finished product. Physically, from this standpoint, an oil should have a light color. Highly refined oils are usually of a pale straw hue; and as spindle oils fall in this classification, they have inherently one desirable feature easy to control.

The spindle oil should be resistant to vaporization and viscosity change in service. Methods of refining crude oil include its subjection to high temperatures to drive off the lighter and lower viscosity components which are not suited to spindle lubrication. This process removes many impurities and further treatment will yield a product that has the qualification of a good spindle oil with resistance to vaporization. An oil of a given viscosity can be made by the blending of oils of a high and a low viscosity in the proper proportions, but the evaporation of the higher volatile oil would occur first and leave an oil of considerably different viscosity than the original. For this reason the best spindle oils are those that are "heart cut"; that is, produced close to the same point in the refining process. A "heart cut" is the best which can be refined from the crude within the required viscosity range.

Since spindles of modern spinning frames operate at higher speed than they did several years ago, the spindle oil must serve a new function. It must serve as a shock element or buffer to prevent vibration and hunting at high speeds. The design of bolsters to entirely eliminate this has not been possible; accordingly, the oil is used as a shock absorber assistant.

The condition of the bearing surfaces of the spindle blade and bolster are important to best performance. A fine finished surface is ground onto the spindle blade, but the bolster cannot be machined with this precision. This polish must be brought about by running in. The fine finished surfaces permit the use of thinner and more uniform oil films which produce less friction and better dampening effects respectively.

The spindle runs at high speeds and is designed with close clearances to eliminate wobbling tendencies. Thus it is necessary to use very light oils in order that the flow into the pressure area may proceed without interruption. Also, a plentiful reservoir is necessary to supply the pressure area. If the oil is too heavy in body, it cannot easily follow the spindle; and the consequent oil drag produces excessive fluid friction which heats up the bearing. This continues until the oil reaches a temperature that makes it thinner and better able to follow the spindle. The action is objectionable and may occur with light spindle oils if they possess too much of a mysterious property called oiliness.

In review of the factors that must be met by a good spindle oil, unit power consumption may be secondary to other factors if continued efficiency is to be maintained. In summary the oil should be resistant to vaporization, show minimum increase in viscosity, have a low corrosive tendency, and further be easily removable from the yarn. If these are satisfied, an oil should be selected that prevents wear with the least fluid friction as long as vibration can be held to a minimum.

Purpose of Investigation:

In the light of previously published information, the author felt that definite information on the power consumption of textile spindles and its relation to lubrication was lacking. The efforts of this investigation therefore were concerned with:

1. Determining if worthwhile power savings can be gained by using oils of lower viscosities on the average spindle,

2. Presenting data on the general power characteristics of the textile spindle,

3. Presenting an easy and accurate method by which power and related characteristics of new and different types of spindles may be checked in the testing laboratory of the average mill, and

4. Observing and correlating as many of the other variables peculiar to the textile spindle as possible.

Scope:

Numerous power breakdowns have been made in the past using an entire spinning frame, but very little information has been presented as to requirements of a single spindle. With this realization and the objectives stated above in mind, this study was limited to investigations of a single spindle operating at speeds ranging from 4,000 to 9,000 rpm with packages varying in size from a bare bobbin to a full package. The type of spindle chosen was one with a cast iron bolster and an oil reservoir. This type is used predominantly in the mills today. Further, the experiments were made separately from the spinning operation; i.e., with pre-spun packages.

The extreme difficulty in obtaining accurate data of the small amounts of power required by a single spindle has no doubt discouraged on-the-spot mill checks of spindle problems and accounts for the meager data available on the spindle performance. Therefore, a dynamometer capable of making these checks and its application in any textile research department will be described in this report.

DESCRIPTION OF TESTING EQUIPMENT

Before any information could be obtained related to the main objectives of this investigation, it was necessary to design or find a suitable means of measuring small amounts of power. Estimates of the amount of power used by a spindle ranged from five to twelve watts; these estimates were later found to be low. Some type of dynamometer seemed to be the answer, but a survey of the literature on conventional testing methods failed to produce anything to handle the problem. Since any type of dynamometer used would require vertical mounting, by the nature of the spindle position, the problem of measuring the torque was complicated. In this position it was necessary to measure a horizontal force which eliminated the ordinary type scales or balances. These considerations resolved the problem to finding an extremely sensitive dynamometer and a means to measure torque.

Several attempts were made to design a frictionless mounting of the oil reservoir of the spindle assembly which would allow freedom of rotation and measurement of the torque. The difficulties involved too much friction in the mounting, insufficient support of the spindle at high speeds, inaccurate torque measuring devices, and the eccentricity of the spindle in the mounting due to loose fit of bolster in the oil reservoir. For the latter the belt tension pulled the bolster a small distance out of the center of the mounting, and erroneous torque values were recorded.

The dynamometer design finally used is pictured in Figs. 1 and 2. The details of this dynamometer were furnished by courtesy of Mr. Earl Heard, vice-president in charge of research, and Mr. Herman Grandberry, head of the mechanical department, West Point Manufacturing Company, Shawmut, Alabama. The dynamometer proved very satisfactory for this type of testing, and it should have application in any mill desiring to make a study of their spindle problems.

The dynamometer consisted of a small electric motor mounted on a bracket and suspended by a music wire used as a torsion meter. Speed of the motor was regulated within very close limits by a Variac resistor. The speed readings were taken on the spindle by a stroboscope and were checked with a hand tachometer.

To assure dynamometer measurements unaffected by friction, careful fitting and alignment of all parts were necessary. The electric motor (see Figs. 1 and 2) was mounted on the motor support bracket and supported from the top of the main frame by a four inch long music wire. The shafts of the motor support bracket were free to rotate in No. 6202-2Z S.K.F. ball bearings. The fit of these shafts in the bearings was a light hand press fit which allowed the music wire and not the bearings, to support the load of the motor and its bracket. The fit of the ball bearings in their supports was only sufficient to prevent their falling out under their own weight. The torsion or music wire was soldered in brass plugs and attached to the upper motor support shaft and to the main frame by means of set screws.

The tests were made using standard mill packages of 0, 38.5, 68.5, and 100 per cent of full package as shown in Fig. 3. Also shown in this figure is the thermocouple wire used to determine oil temperature during test. The thermocouple was inserted through the oil filler passage into the oil reservoir between the bolster and the wall of the reservoir.

The essential items of testing equipment were as follows:

1/10 hp., 115 volt, AC-DC, 7,000 rpm, series type electric motor.

2¼ inch motor pulley.

125 volt, 2 amp. Variac resistor.

2 3/4 inch SKF SR type tension pulley.

0 to 150 °F Wheelco potentiometer.

Iron-constantan thermocouple.

0 to 120 °F mercury thermometer.

Bolster type spindle with 1¼ inch whorl.

4 bobbins, net weight of packages 8.58 oz., 5.84 oz., 3.30 oz. and 0 oz.

5 oils of different viscosity (complete data is given in Table VIII).

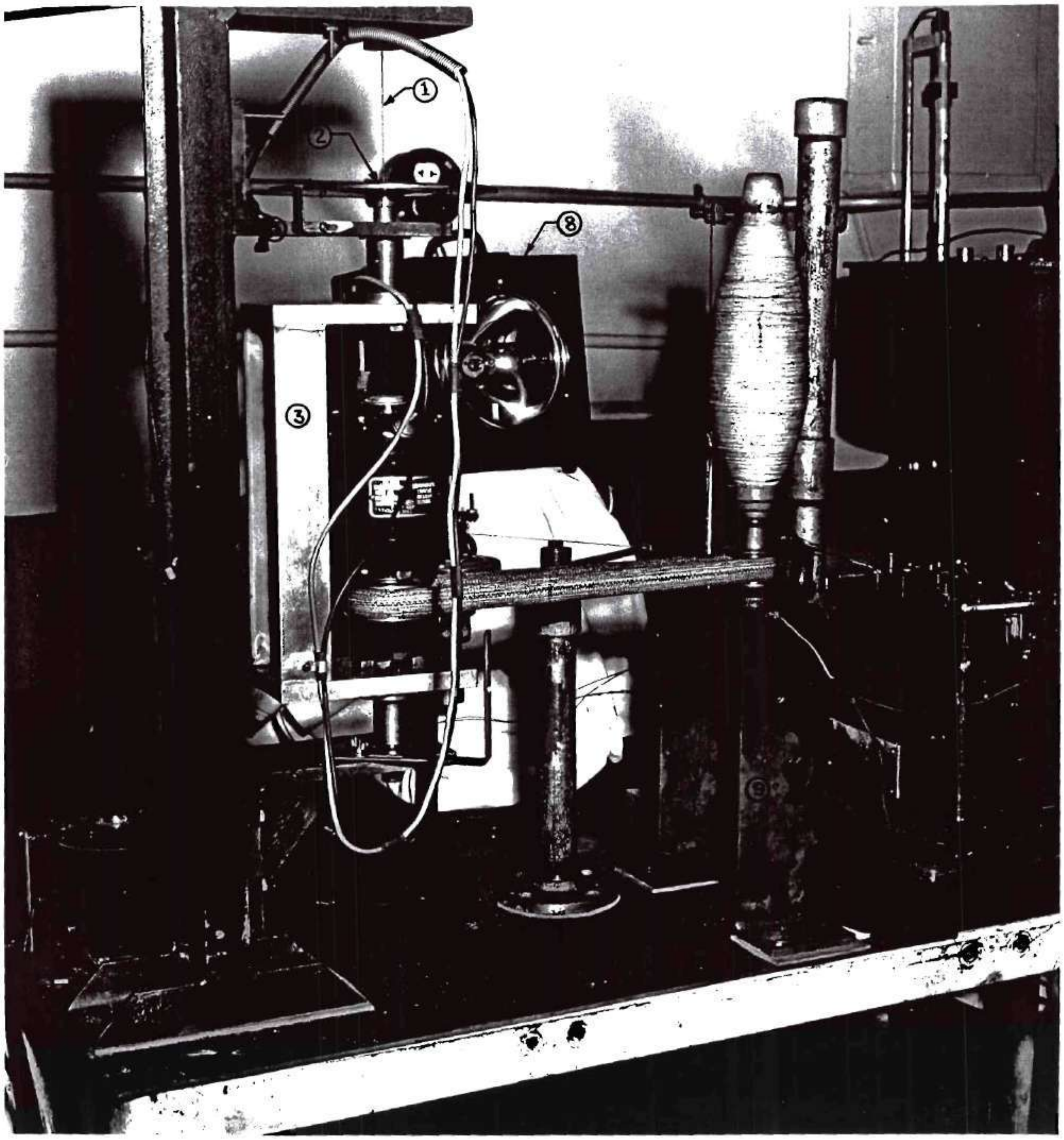

FIGURE 1. SINGLE SPINDLE DYNAMOMETER

1. Torsion Wire
2. Dial
3. Motor Support
4. Main Frame
5. Upper Support Bracket
6. Lower Support Bracket
7. Variac
8. Stroboscope
9. Spindle Support

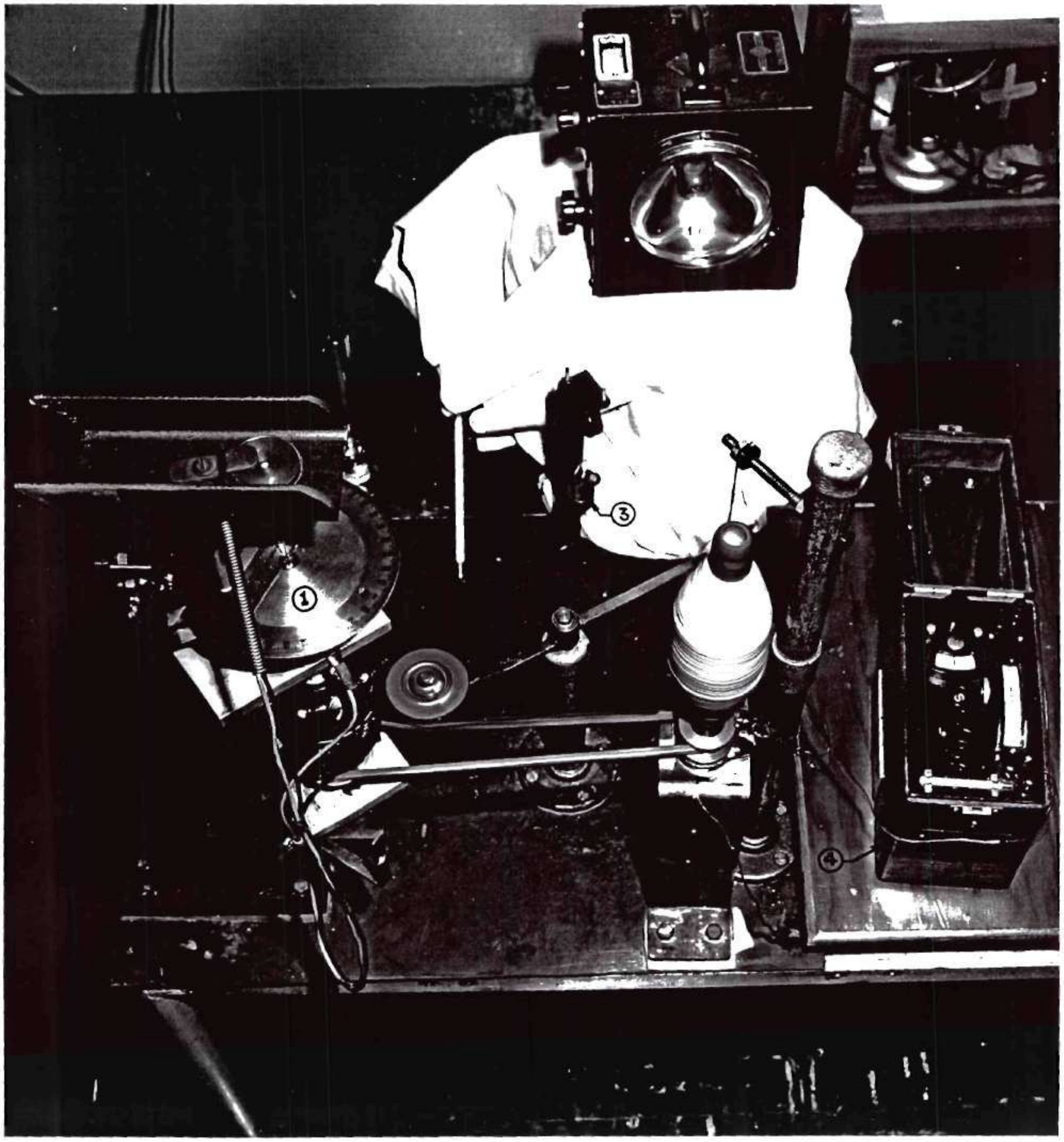

FIGURE 2. TOP VIEW OF SINGLE SPINDLE DYNAMOMETER

1. Dial
2. Tension Pulley
3. Tension Weights
4. Potentiometer

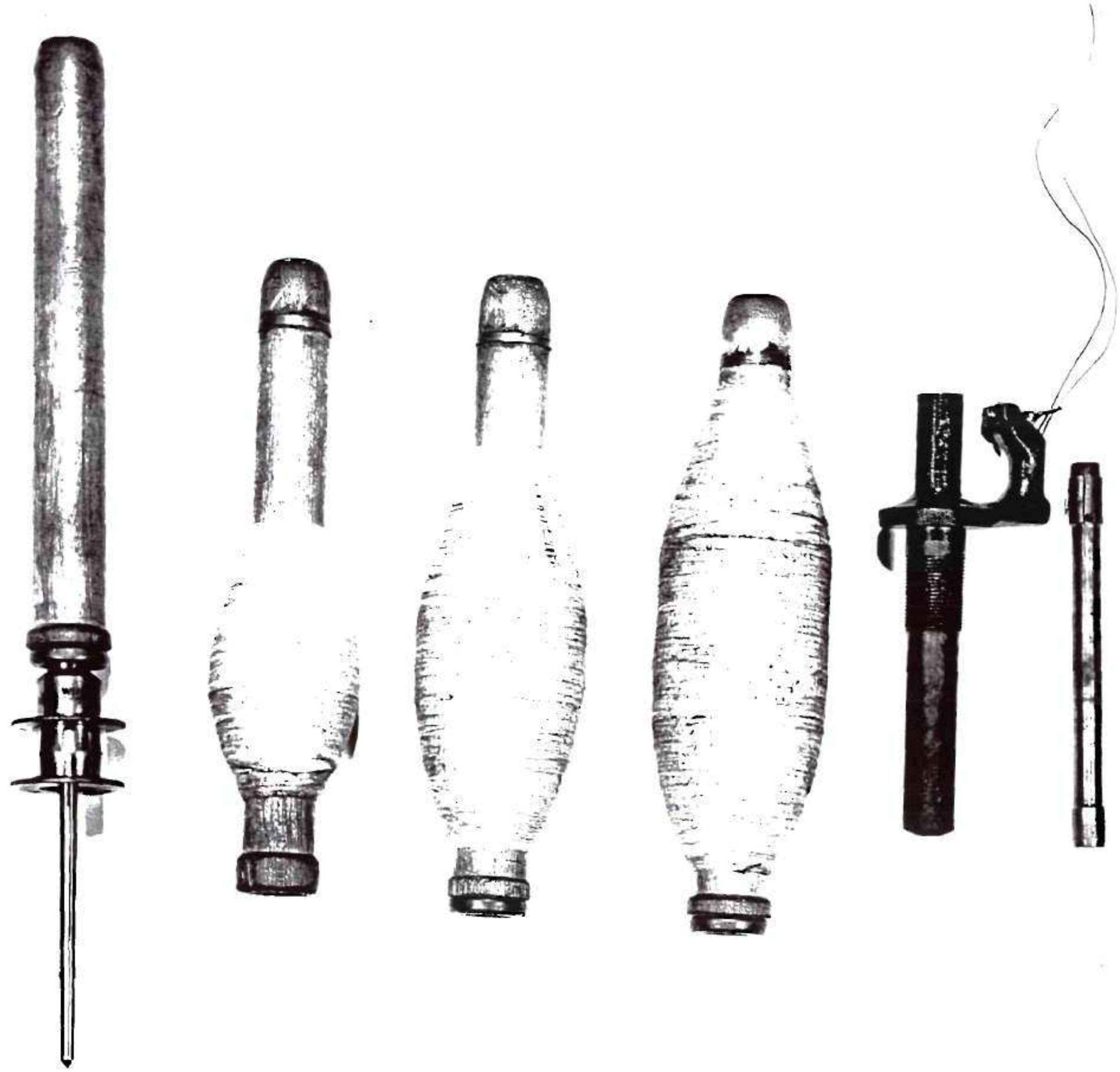

FIGURE 3. SPINDLE, BOBBINS, OIL RESERVOIR, AND BOLSTER

TEST PROCEDURE

Because of the wide range of viscosities that an oil exhibits with variations of temperature (see Fig. 16), these tests were carried out in the air conditioned laboratory of the textile building at Georgia Institute of Technology. The room temperature was maintained from 74° to 77° F.

The testing was made on five straight run mineral oils ranging in viscosity from 216 to 70.8 seconds Saybolt Universal Viscosity at 100° F. Complete physical data of the oils are given in Table VIII and Figs. 15 and 16. Each oil was tested at 4,000, 5,250, 6,500, and 9,000 rpm using packages of 0, 38.5, 68.0, and 100 per cent of full weight of yarn on the bobbins. A static tape tension of one pound was maintained by a force applied to the tension pulley by means of a dead weight applied on the arm of the tension pulley.

At the beginning of each test, the torsion dial was checked for zero; then the motor was turned on, and the spindle brought to 4,000 rpm as determined by a stroboscope. The spindle was operated until the oil in the spindle base reservoir reached an equlibrium temperature. This generally required about 30 to 40 minutes for the first run and 15 minutes for each speed thereafter. When equilibrium had been established, the degrees twist of the torsion wire was recorded along with room temperature and oil temperature. After this, the spindle speed was brought to 5,250 rpm and equilibrium established before recording the data for that condition. The procedure was repeated for 6,500, 7,750, and 9,000 rpm.

The second, third, and fourth portions of the test were repeated, as described above, for the other packages. After a complete set of data had been determined for the four packages, the entire procedure was repeated as a check on the first tests. The second set of data was checked to see that it agreed with that of the first. If satisfactory agreement was not noted, several additional tests were made until the data compared favorably.

When satisfactory checks of the first test had been completed, the spindle and base were removed; and the oil was cleaned from all parts of the assembly with carbon tetrachloride. The parts were then thoroughly dried and filled with oil for the second tests, and the procedure repeated.

To eliminate the effect of the power consumed by the tension pulley and belt, a test was made driving the tension pulley with the same belt tension as used in the spindle tests. The proper values of torque determined by this test were deducted from the value obtained in the spindle test to calculate net power in the final results.

The torsion wire used as the torque meter was calibrated by comparing the reading on the dial with gram weights suspended by a thread which ran over a pulley and was wrapped around the lower motor support bracket shaft. From these data, a calibration curve was drawn (Fig. 14), and the torsional modulus of elasticity of the wire was calculated (see p. 55). The value of the torsional modulus was found to be 12.17 x 10^6. It is interesting to note here that this value checked closely with the values of 11.2 to 12.5 x 10^6 listed in handbooks as the torsional modulus of elasticity of music wire.

DISCUSSION OF RESULTS

The characteristic power requirements of the sleeve bearing type textile spindles are primarily affected by the following variables:

1. Speed of the spindle.
2. Size of the package.
3. The lubricant.
4. Weight of the package.
5. Tape tension.
6. Spindle vibration and wobble.
7. Condition of bolster and spindle blade.

The power to overcome yarn tension is part of the job of the spindle. This power is something that cannot be reduced without making a softer bobbin, because it is directly dependent on the tension in the yarn between the traveler and the bobbin. It is the resultant of the centrifugal forces of the traveler and balloon, friction, and windage. Lowering one or the other of the forces means increasing another to maintain the same density bobbin. For this reason, yarn tension is not listed with the above variables, and its effect on this test was eliminated by using pre-spun packages at various stages of completion.

As these tests were made on a single bolster and spindle that had been properly broken in, this variable was eliminated. During all of the tests, a constant check was made on the vibration and wobble. This observation failed to show anything that might be considered detrimental to good spinning or tend to increase power requirements.

A description of the methods used to investigate vibration and wobble will be given, although the results of their measurements were not conclusive and are not included in this report. The ends of the spindles were equipped with metal collars electrically grounded through the spindle shaft which allowed a micrometer fixed at the level of the collar to be adjusted to complete the electrical circuit and light a small bulb. The amount of the movement of the micrometer required to complete the circuit was used to measure the amplitude of the wobble. The vibration element of a vibration meter was attached to the spindle mountings support, and the amount of acceleration, velocity, and displacement was measured. The values obtained from these instruments did not follow any definite pattern of variation nor did their magnitude compare to what is known as a "wobbly spindle" in the mill. Probably the reason for indifferent pattern of the readings was the large difference in speed of the tests. It would be expected that some definite relation might be obtained by readings made at closer intervals of speed.

The power consumption of the spindle may be affected appreciably by excessive tape tension, and only sufficient tension to keep the tape taunt is recommended (10). The tape tension used throughout this investigation was one pound which is the most recent estimate of the value to use. It is somewhat less than the tension generally used in the past.

For full fluid film lubrication, which is the case of the textile spindle, the power consumption is affected very little by a small change in weight. In a test made by the Saco-Lowell Shops (10), a 3.1 per cent increase in power was noted in the operation of a spinning frame with bare spindles than with empty bobbins. This increase is caused largely by the greater windage of the rotating bobbin over the smaller bare spindle rather than the actual differences in weight.

The effect of the last four of the variables listed as the predominant factors affecting the power has been shown to be a constant or small in comparison to the others for these tests. The efforts of this investigation were directed toward finding the effect of the first three; namely, spindle speed, size of package, and the lubricant.

Figs. 4, 5, 6, and 7 show that the lubricant does not change appreciably the general characteristics of the power curves. The effect is mainly a reduction in power with reduction in viscosity. Because of the close similarity of these curves, the remaining comparison will be made from the data on the 183, 102.6, and 70.8 secs. S.U.V. oil.

The effect of speed and size of package on power are interrelated, and it is difficult to separate them. The curves of Figs. 8, 9, 10, and 11 represent the relation of the speed and size to the power. It is interesting to note in the curves

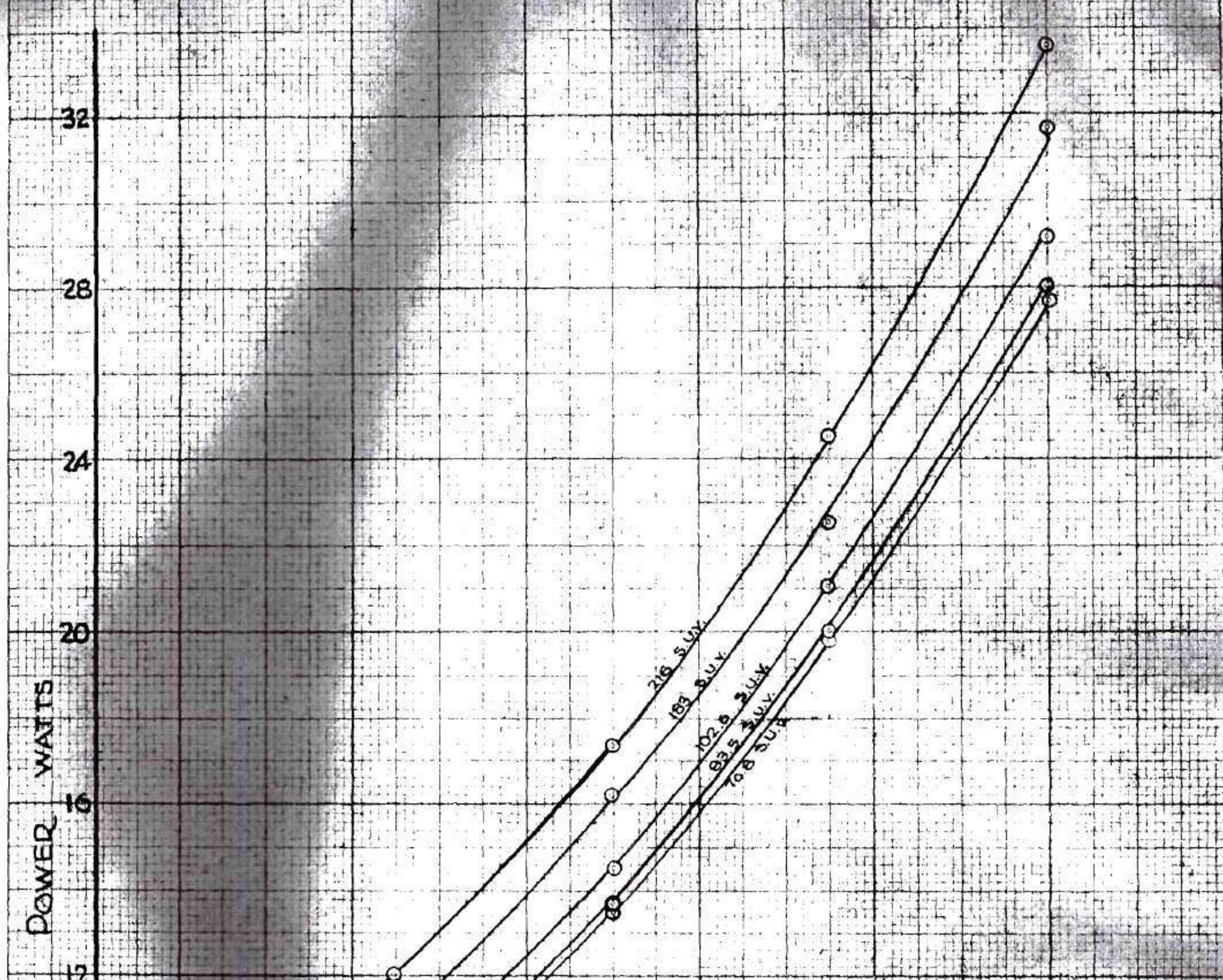

FIGURE 4
TEXTILE SPINDLE
POWER-SPEED CURVES
FULL PACKAGE VARIABLE VISCOSITY

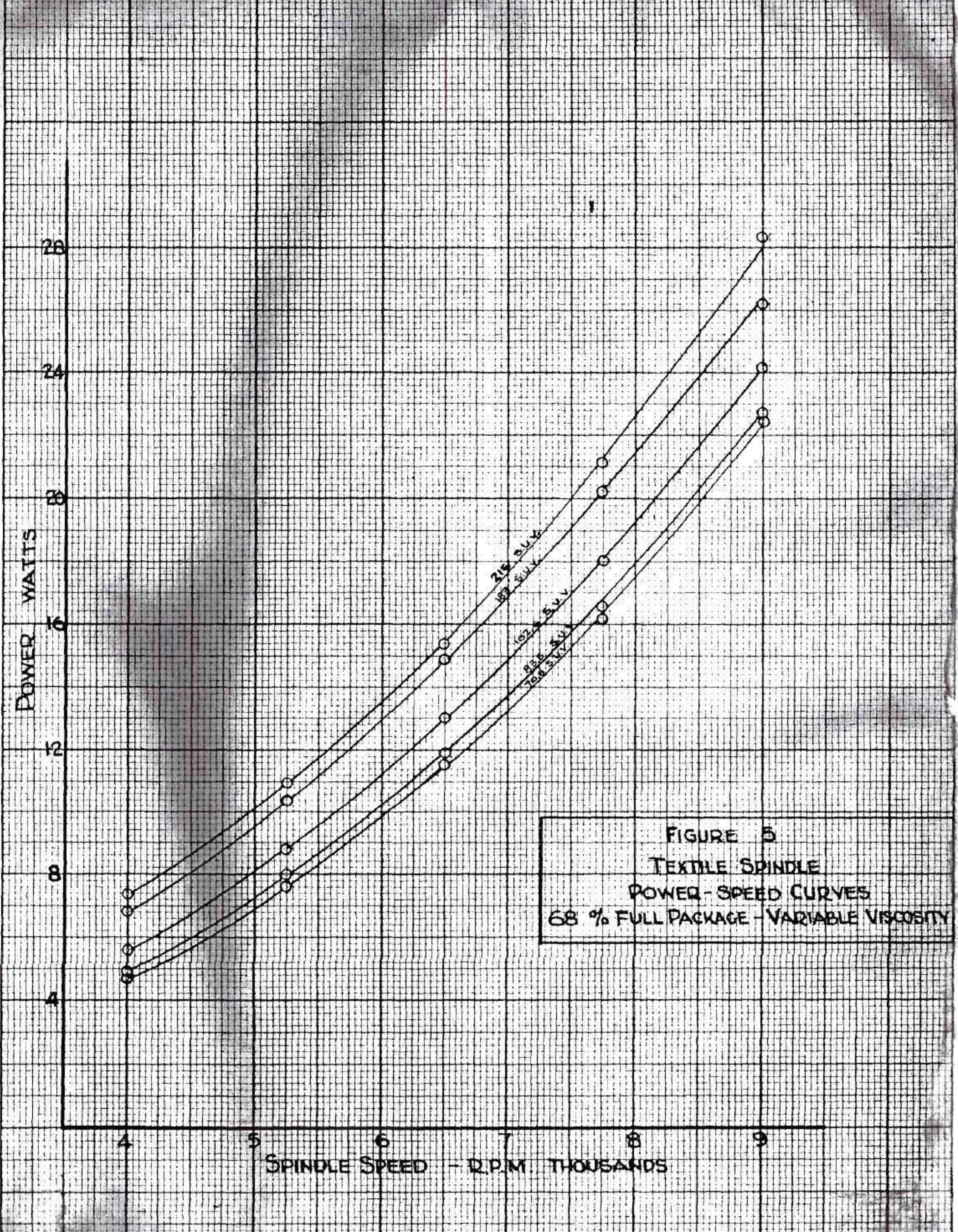

FIGURE 5
TEXTILE SPINDLE
POWER - SPEED CURVES
68 % FULL PACKAGE - VARIABLE VISCOSITY

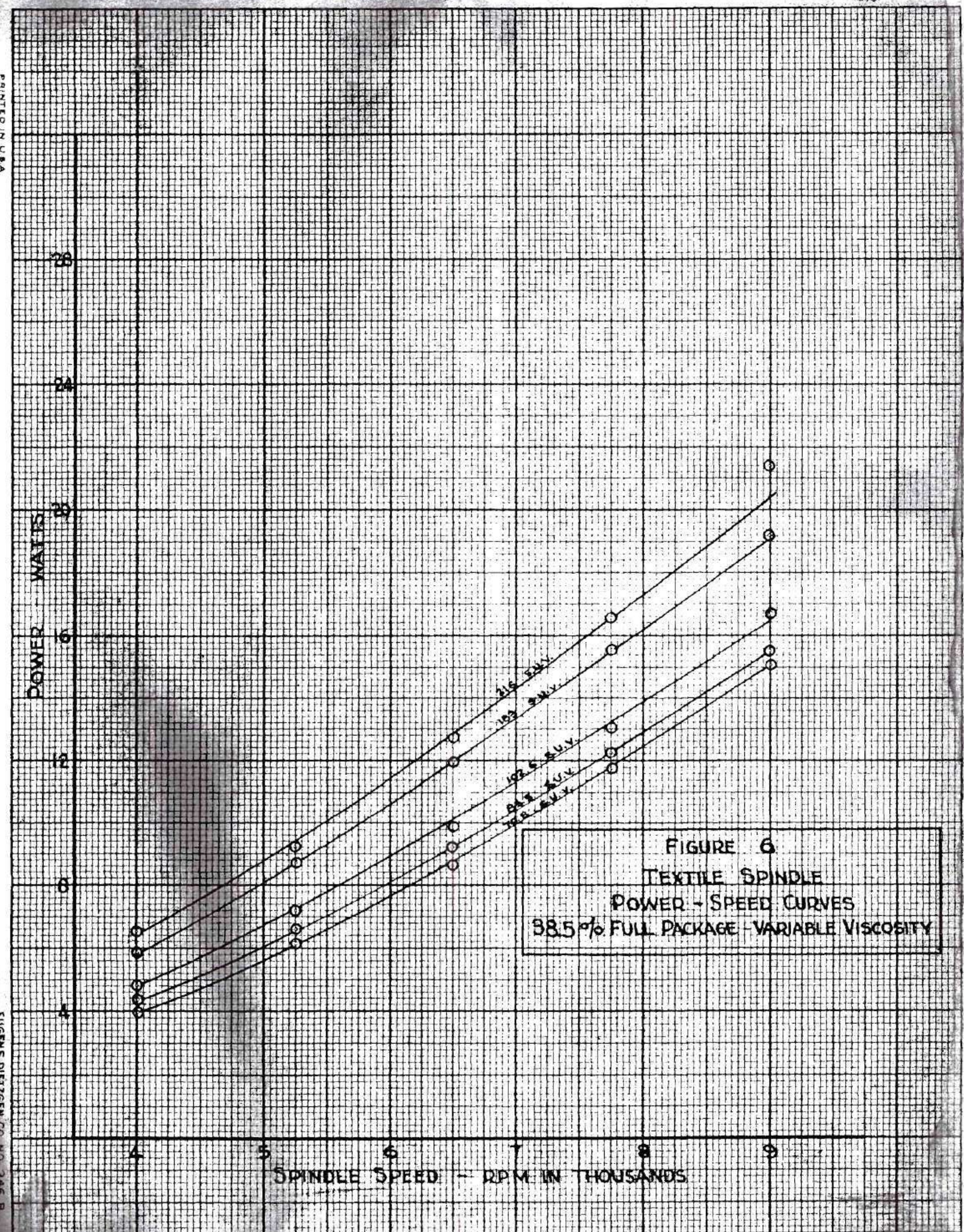

FIGURE 6
TEXTILE SPINDLE
POWER - SPEED CURVES
38.5% FULL PACKAGE - VARIABLE VISCOSITY

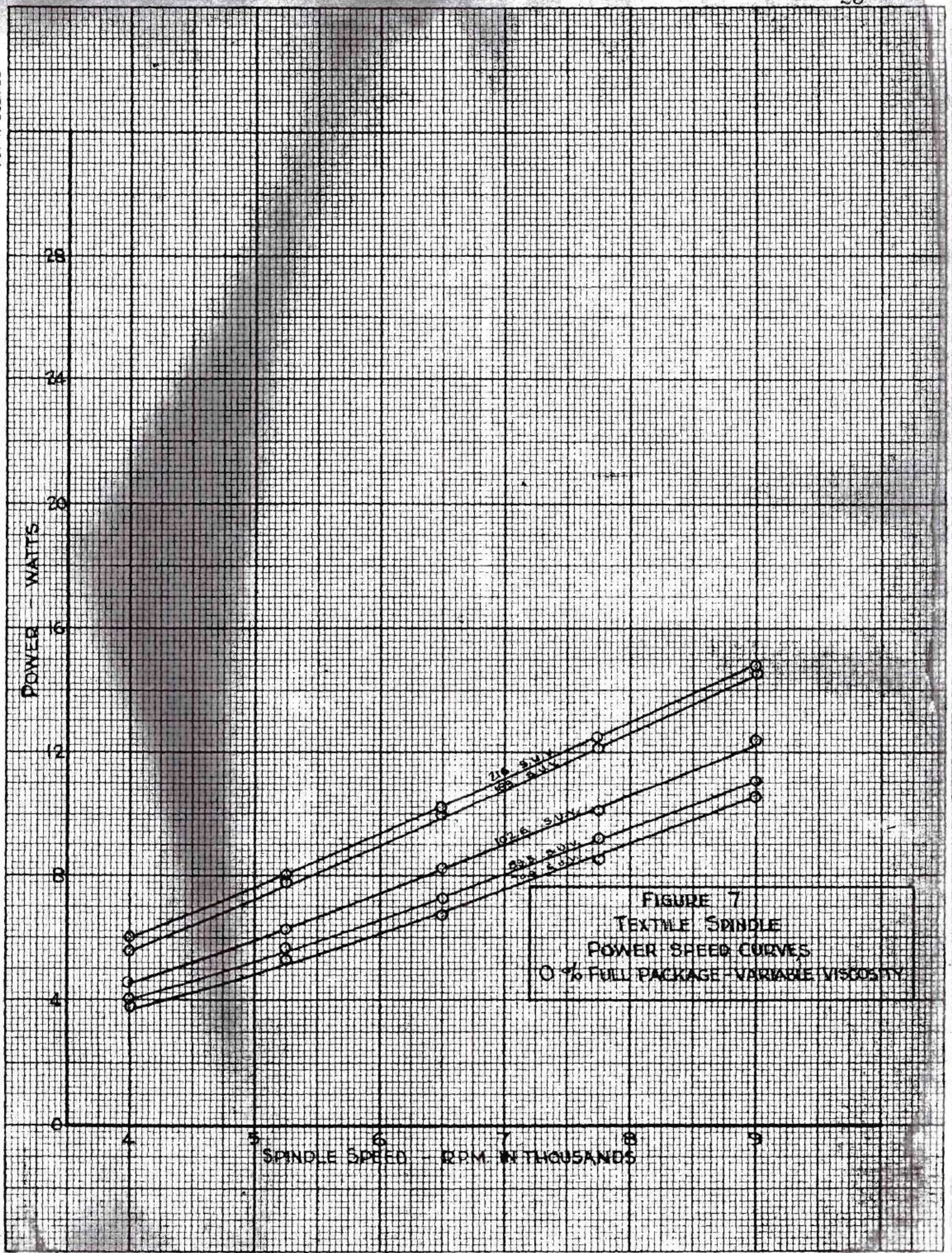

FIGURE 7
TEXTILE SPINDLE
POWER SPEED CURVES
0 % FULL PACKAGE - VARIABLE VISCOSITY

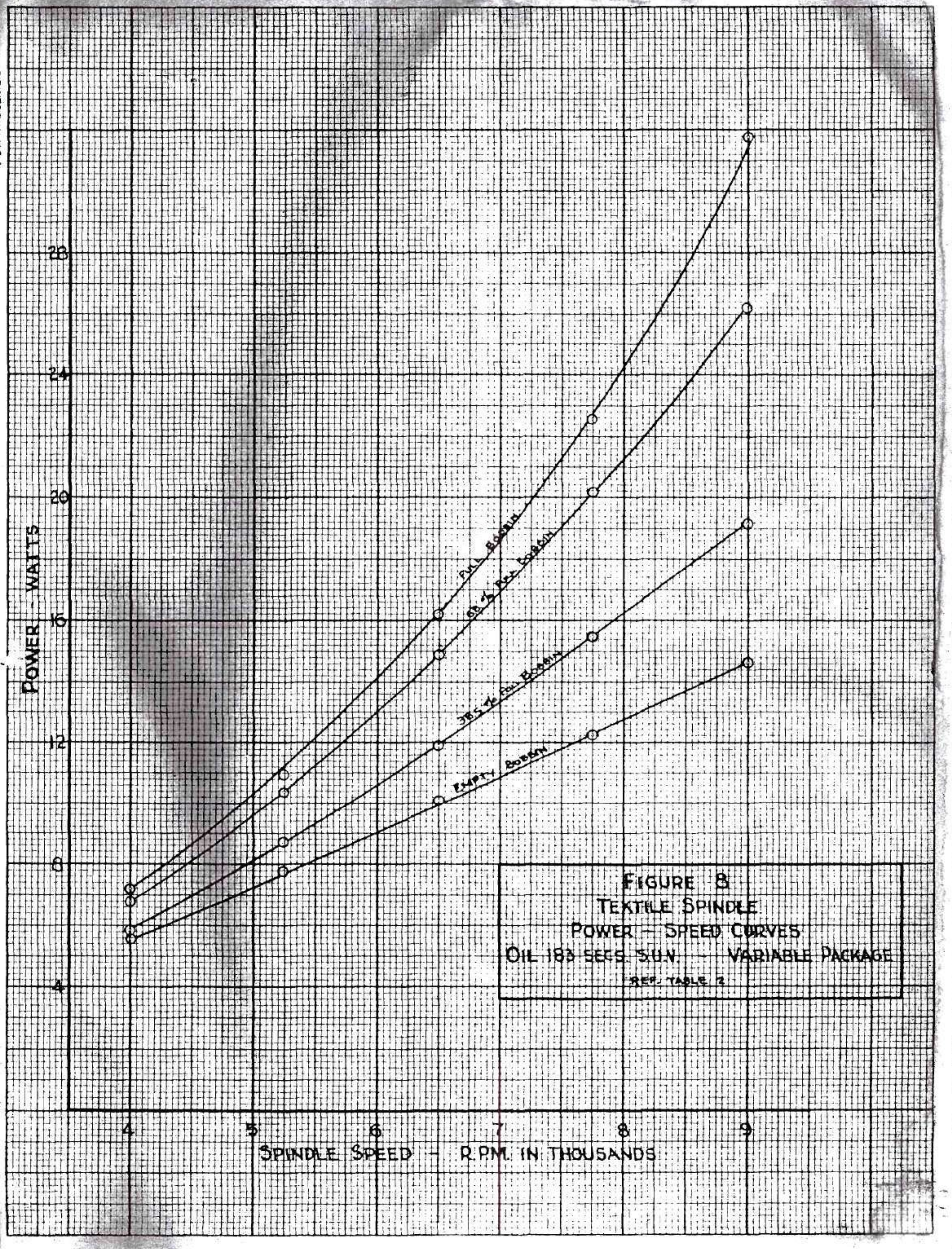

FIGURE 8
TEXTILE SPINDLE
POWER - SPEED CURVES
OIL 183 SECS. S.U.V. - VARIABLE PACKAGE
REF. TABLE 2

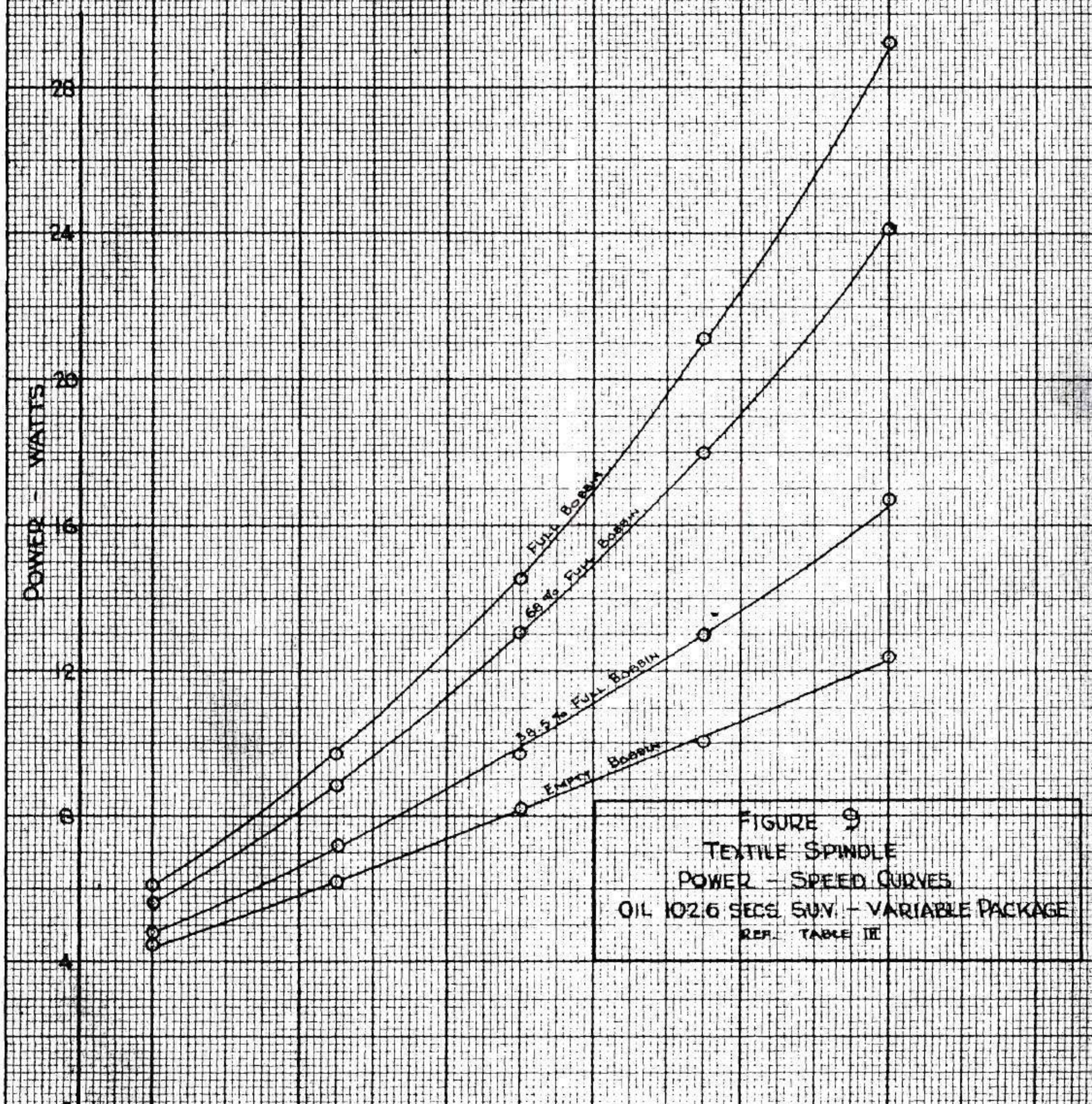

FIGURE 9
TEXTILE SPINDLE
POWER - SPEED CURVES
OIL 102.6 SECS. S.U.V. - VARIABLE PACKAGE
REF. TABLE III

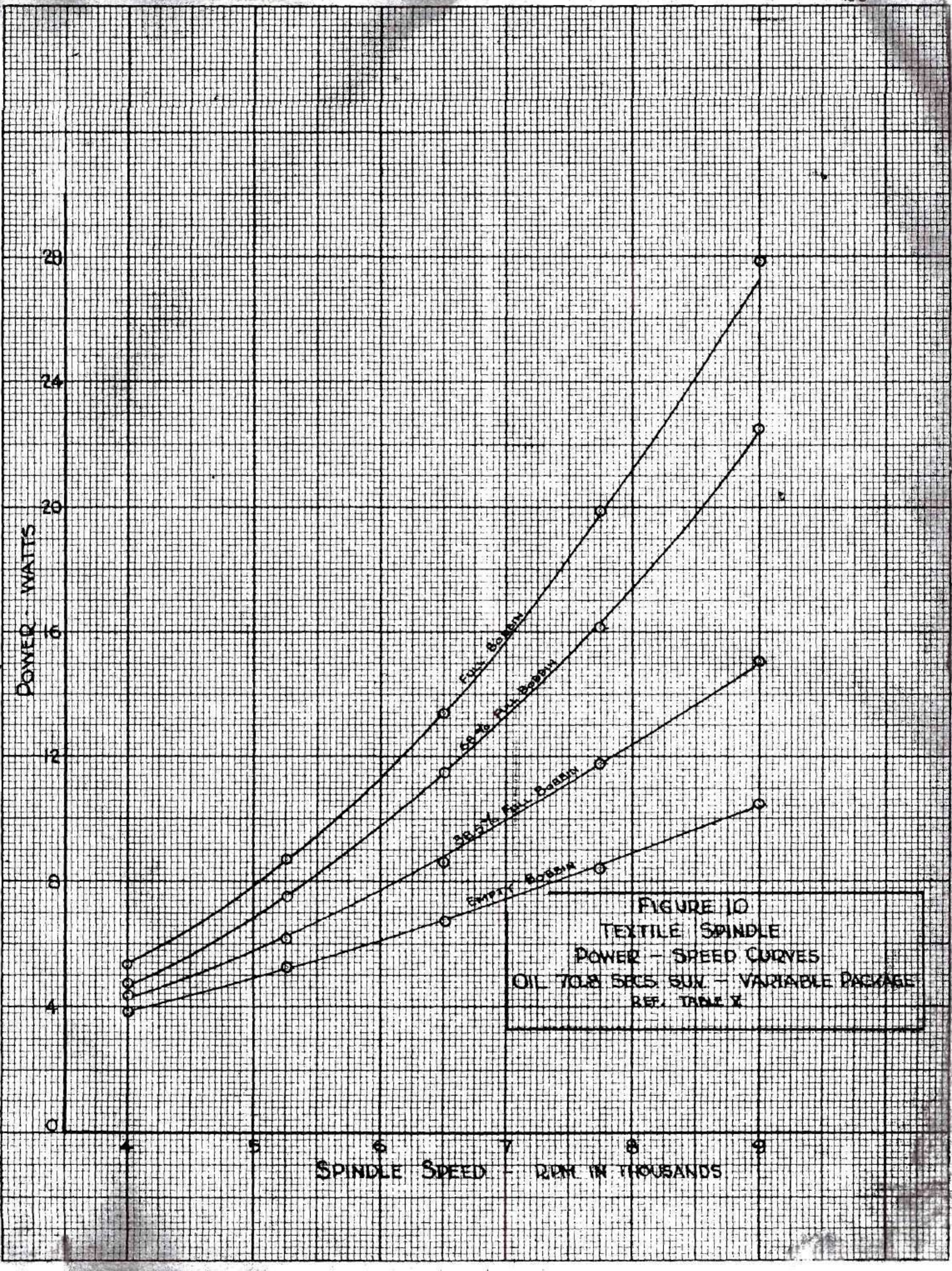

FIGURE 10
TEXTILE SPINDLE
POWER - SPEED CURVES
OIL 70.8 SECS. SUV. - VARIABLE PACKAGE
REF. TABLE X

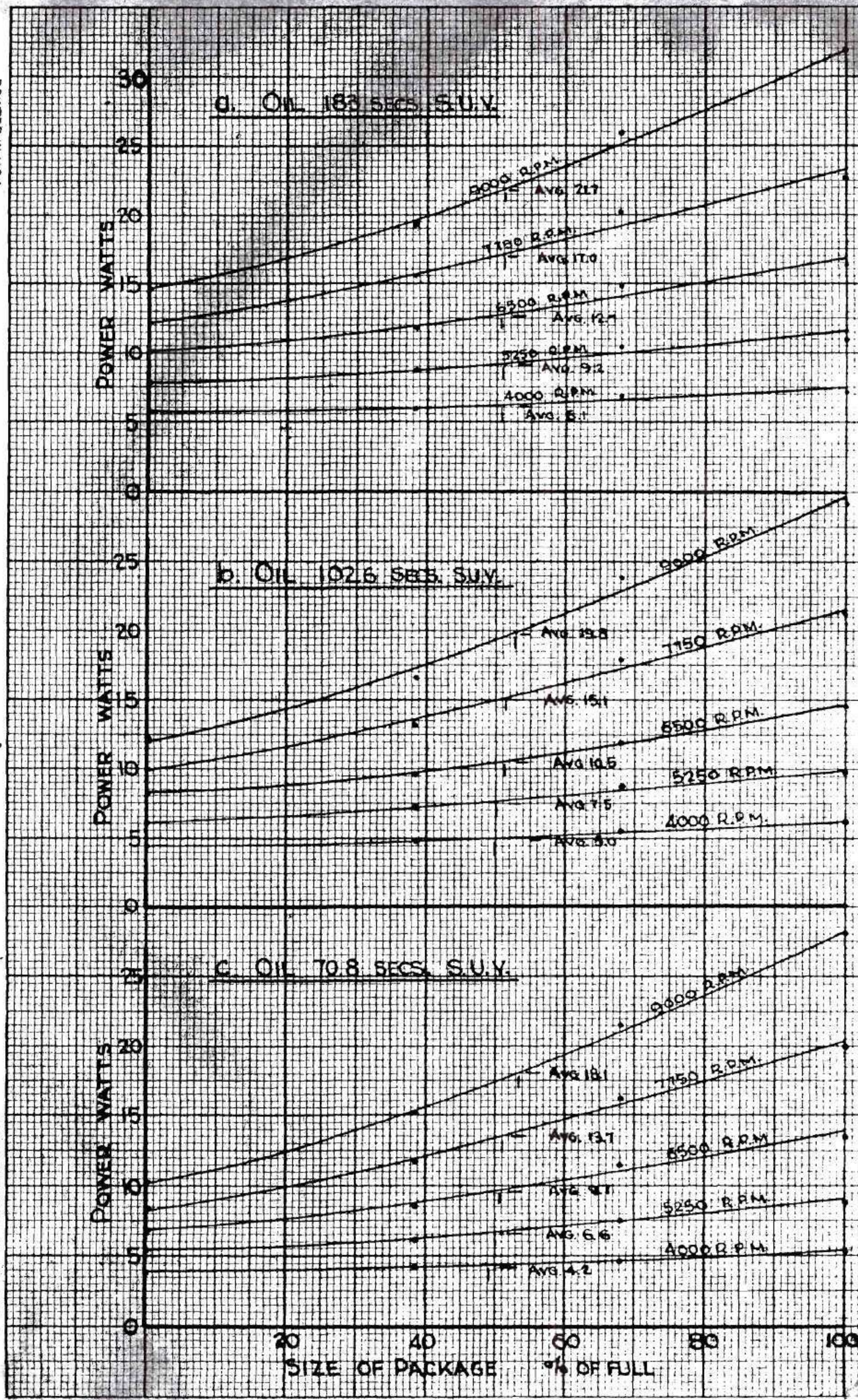

FIGURE 11
TEXTILE SPINDLE POWER-SIZE OF PACKAGE CURVES

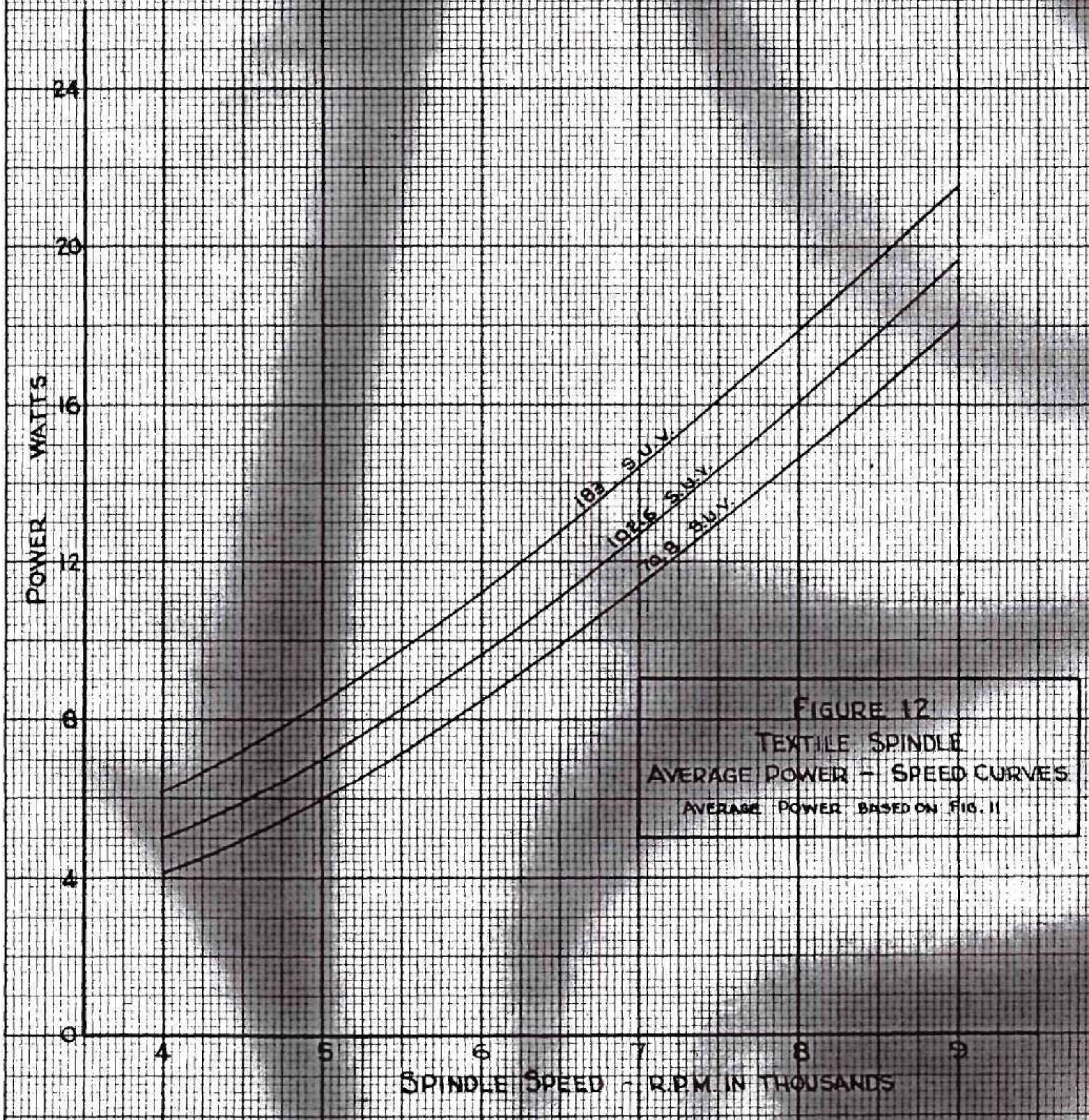

FIGURE 12
TEXTILE SPINDLE
AVERAGE POWER - SPEED CURVES
AVERAGE POWER BASED ON FIG. 11

of Figs. 8, 9, and 10 the rapid increase in power as the size of the package increases from zero to full bobbin. For an empty package this variation is almost a straight line with the power required at 4,000 rpm being about three-eights of that at 9,000 rpm. For the full package this ratio is about one-fifth. The rate of increase changes from the approximate straight line to a relation that is almost the cube of the speed.

Figure 11 shows the relation of the power to the size of package at a given speed. These curves indicate that there is a forty to sixty per cent increase in power from empty to full bobbin with speeds of 4,000 and 5,250 rpm. As the speed increased above 5,250 rpm, the power rose very rapidly, and at the higher speeds increases of two to three hundred per cent are found.

The average power curves of Fig. 12 were drawn by determining the average ordinate of Fig. 11 and plotting the values against speed. Analysis of these curves permits an easy method to find the average amount of power to drive the spindles. For each 20,000 spindles using the 70.8 secs. S.U.V. oil, the amount of power required to drive is given as follows:

4,000 rpm - 80 kw.
5,250 rpm - 132 kw.
6,500 rpm - 194 kw.
7,750 rpm - 274 kw.
9,000 rpm - 362 kw.

These values show the proportions that the power increases with speed. It is to be remembered that these values are only a portion of the total required power and that the increasing amounts of power required of the rotating parts, such as cylinder, tape, pulley, balloon, and traveler, will be in somewhat the same ratio.

The previous analysis shows the effect of the size of the packages and their speed on the power consumption of a spinning frame. This item should warrant full analysis by the management of a mill before increasing either.

There are many good reasons for operating spindles at high rotative speeds and spinning packages of a fixed size and weight. In this case the speed and package cannot be considered a variable. If tape tension, vibration and wobble, and condition of bolster and spindle blade are all kept under control, there is but one element left to discuss as a power consumer; namely, the lubricant used. As was pointed out in the introduction, a good lubricant for textile spindles must perform several functions and meet rigid specifications; however, from the standpoint of a power saver, the most important property is viscosity. Of all the items discussed as affecting the power, the lubricant is by far the easiest to control; as all that is necessary is to fill the spindle base with the proper lubricant and to check it about every 1,000 hours.

The effect of the lubricant as a power saver is often scoffed at by textile men. The general opinion exists that the only function of the lubricant is to prevent wear and dry friction, and any oil that will accomplish this is satisfactory. Mills have had a tendency to use oils with viscosities higher than those recommended which probably stems from "spinning room lore," that spindle wear is reduced. A basic principle of lubrication shows that there is no wear with full fluid film lubrication. If this can be accomplished and vibration prevented at the same time, the oil of the least viscosity will be the best.

This investigation was designed primarily to show that worthwhile savings of power could be accomplished from the use of oils of lower viscosities. The results for all five of the oils tested are presented in Figs. 4, 5, 6, and 7. A study of the curves in each figure shows that the essential effect of using an oil of lower viscosity is to reduce the power requirements. However, slightly greater changes are indicated at the upper speed than at the lower speeds which is contrary to theory. Normally, in view of viscosity differences in the oils at low temperature than at the higher temperature (see Fig. 16) the opposite would be true. This trend was shown throughout the tests; but since the variation is small, it might be said that the amounts are not within the accuracy of the dynamometer and verification should be checked on a still more accurate instrument than the one used here.

To avoid confusion, average power curves were plotted, as already described, for only the 183, 102.6, and 70.8 secs.

S.U.V. oils. If we again choose 20,000 spindles for a comparative study, the amount of power saved for oils of S.U.V. between 183 and 102.6 secs. varies from 24 kw. at 4,000 rpm to 38 kw. at 9,000 rpm. The power reduction obtained by lowering the viscosity from 102.6 to 70.8 secs. amounts to 19 kw. at 4,000 rpm and varies to 30 kw. at 9,000 rpm.

Certainly even the minimum of these savings is worth - while and would affect production costs by decrease in maximum demand charge and kilowatt hours consumed.

Previous data which were studied for confirmation of these values show slightly greater savings. Most of these data were obtained on producing mill machinery or from a spindle dynomometer with weighted spindles rather than the typical mill package. For the test on the entire frame, there are too many variables for conclusive results; and for the latter, ficticious values could result by reducing the greatest power effect, windage, a factor which is largely dependent on the area and roughness of the surface.

The possibility of using an oil of still lower viscosity is surely worth consideration; but as the 70.8 secs. S.U.V. oil was the lowest investigated, a definite statement as to how much cannot be made. However, in one instance during a breakdown of the air conditioning machinery, the room temperature was several degrees higher than usual. A few checks were made on the 70.8 secs. oil with operating temperature above normal. Higher than usual vibrations were recorded at the two top speeds; further the spindle speed and the dynamometer readings were unsteady. A reasonable conclusion is that at the higher speeds the 70.8 secs. oil was near optimum for the spindle used.

There were a few incidental points observed during this test worth mentioning. One relates to oil throw, an undesirable characteristic of any textile machinery, as it may cause a staining of the yarn or cloth that is difficult to remove. Throughout all of these tests, an attempt was made to see to what degree this might occur. The top of the spindle support bracket was cleaned with carbon tetra-chloride at the beginning of each test and periodically checked during the test for traces of oil. On only one occasion was there any discernible oil on this surface. On further check it was found that the oil reservoir had been filled with too much oil and expansion of the oil due to the temperature rise caused it to overflow. On the basis of the observations of these tests, the spindle has been accused of oil throw as a result of too much oil in the reservoir or possibly because of wobbling spindle as others have pointed out (17).

Another fact observed during this test has to do with the break-in period recommended by most spindle manufacturers. Since the bolster surface cannot be machined with the precision of the spindle, for it is made of cast iron, the polish of the bolster must be brought about by running in. After the run-in period preliminary to these tests, the oil used was poured into a beaker. It was found to have darkened considerably and contained small particles of scale and iron. These small particles were abrasive and would lead to wear; therefore, the oil used during the break-in period should be discarded and the oil reservoirs replenished. Darkening of the oil and abrasive particles were not found in the oils in any of the following checks.

The temperature difference of the spindle oil and the surrounding room has been used as a gage of currect viscosity of the spindle oil. From results of temperature measurements made here, such a conclusion is a poor criterion. Extreme viscosity differences could be determined roughly on this basis; but to distinguish among a 183, a 102.6, and a 70.8 secs. S.U.V. oil, as used here, would be practically impossible. Even though room temperature varied only from 74° to 77° F, consistent data of the oil temperature between bolster and oil reservoir wall could not be obtained. Some of the inconsistency no doubt lies in the difference in air movement in the room which affected the heat dissapating characteristics of the oil reservoir.

CONCLUSIONS

The following conclusions result from analysis of data and results of this investigation:

1. The power required for driving the textile spindle increases with speed.

2. The power required for driving the textile spindle increases with size or volume of the package.

3. The power requirement of the spindles and the size and speed of the package are interrelated.

a. The change based on a given size package varies from that of a straight line for empty bobbin to a value approximately equal to the cube of the speed as the package increases (see Figs. 8, 9, and 10).

b. The increased power for constant speed and variable package size ranged from a forty to fifty per cent increase at the low speed to two to three hundred per cent at the higher speeds (see Fig. 11).

4. The power required for driving spindles decreases with the decrease in viscosity of the spindle oil used. Power reductions by using lower viscosity oils are worth-while and represent one of the simplest methods of reducing power costs.

5. A spindle dynamometer has a definite application in the testing department of any spinning mill. Some of the important studies possible by its use are as follows:

a. Comparative power requirement of different types of spindles.

b. Power requirements of spindles for changes in speed, weight, and size of package.

c. Optimum oil viscosities.

6. Changing the spindle oil after the break in period is advisable to remove abrasive material.

7. There is no oil throw for spindles that do not wobble if the proper oil level in the reservoir is maintained.

8. Oil temperatures are poor criteria for proper oil viscosities in textile spindles and show only extreme conditions; i.e., excessively low or high viscosities.

RECOMMENDATIONS

A continued investigation of this type using lighter oils would be desirable. After establishing the optimum viscosity using straight mineral oils, the use of additives present definite possibilities and is a factor that has failed to gain much attention. Certainly there is need of comparative data on the advantages or disadvantages of different types of spindles, especially a verification of the 25 to 33% power reduction claimed for ball bearing type spindle.

The dynamometer used in these experiments showed excellent possibilities for measuring the small amounts of power used by textile spindles; however, a few defects that can be easily remedied should be made. Because a poorly soldered wire permits creep, introducing error in observations that is almost impossible to determine, the torsion wire should be fastened by means of a collet or chuck. Another item, fluxuations of line voltage, makes the use of a voltage regulator highly desirable to maintain constant speed throughout a test. The use of a smaller wire for part-load operation would increase the accuracy of the readings.

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APPENDIX I

APPENDIX I

TABLE I: Test Data and Results for Power Required to Drive Spindle Using 216 Secs. S.U.V. Oil

Spindle Speed rpm	Room Temp. °F	Oil Temp. °F	Temp. Diff. °F	Torque, in Degrees of Twist			Net Power watts
				θ_G	θ_T	θ_{net}	
---Full Bobbin---							
4000	75.0	91.5	16.5	41.5	3.5	38.0	7.8
5250	75.0	96.0	21.0	48.5	4.0	44.5	12.0
6500	75.0	101.5	26.5	56.5	4.5	52.0	17.4
7750	75.0	106.5	31.5	66.5	5.0	61.5	24.5
9000	76.0	109.5	33.5	78.0	5.5	72.5	33.6
---68% Full Bobbin---							
4000	77.0	92.5	15.5	39.0	3.5	35.5	7.3
5250	77.0	95.5	18.5	44.5	4.0	40.5	11.0
6500	77.0	102.5	25.5	50.5	4.5	46.0	15.4
7750	77.0	107.5	30.5	58.0	5.0	53.0	21.1
9000	77.0	110.5	33.5	66.5	5.5	61.0	28.3
---38.5% Full Bobbin---							
4000	77.0	92.0	15.0	35.0	3.5	31.5	6.5
5250	77.0	96.5	19.5	38.0	4.0	34.0	9.2
6500	77.0	102.0	25.0	42.5	4.5	38.0	12.7
7750	77.0	105.5	28.5	46.5	5.0	41.5	16.5
9000	77.0	109.5	32.5	52.0	5.5	46.5	21.5
---0% Full Bobbin---							
4000	77.0	92.5	15.5	32.5	3.5	29.0	6.0
5250	77.0	96.5	19.5	33.5	4.0	29.5	8.0
6500	77.0	102.0	25.0	35.0	4.5	30.5	10.2
7750	77.0	105.5	28.5	36.0	5.0	31.0	12.4
9000	76.5	109.5	32.0	37.5	5.5	32.0	14.8

APPENDIX I

TABLE II: Test Data and Results for Power Required to Drive Spindle Using 183 Secs. S.U.V. Oil

Spindle Speed rpm	Room Temp. °F	Oil Temp. °F	Temp. Diff. °F	Torque, in Degrees of Twist			Net Power watts
				θ_G	θ_T	θ_{net}	
---Full Bobbin---							
4000	74.0	88.0	13.0	38.5	3.5	35.0	7.2
5250	74.0	92.5	18.5	44.5	4.0	40.5	10.9
6500	74.0	97.5	23.5	53.0	4.5	48.5	16.2
7750	74.5	101.0	26.5	61.5	5.0	56.5	22.5
9000	74.5	106.5	32.0	74.0	5.5	68.5	31.8
---68% Full Bobbin---							
4000	75.5	89.5	14.0	36.5	3.5	33.0	6.8
5250	75.0	93.0	18.0	42.5	4.0	38.5	10.4
6500	75.0	97.0	22.0	49.0	4.5	44.5	14.9
7750	75.0	101.5	26.5	55.5	5.0	50.5	20.2
9000	74.0	106.5	32.5	62.0	5.5	56.5	26.2
---38.5% Full Bobbin---							
4000	74.5	87.5	13.0	32.0	3.5	28.5	5.8
5250	75.0	92.0	17.0	36.0	4.0	32.0	8.7
6500	75.0	95.5	20.5	40.0	4.5	35.5	11.9
7750	74.5	99.0	24.5	44.0	5.0	39.0	15.5
9000	75.0	103.5	28.5	47.0	5.5	41.5	19.2
---0% Full Bobbin---							
4000	75.0	88.5	13.5	31.0	3.5	27.5	5.6
5250	75.0	93.5	18.5	33.0	4.0	29.0	7.8
6500	75.0	98.0	23.0	34.5	4.5	30.0	10.1
7750	75.0	101.5	26.0	35.5	5.0	30.5	12.2
9000	75.0	104.5	29.5	37.0	5.5	31.5	14.6

APPENDIX I

TABLE III: Test Data and Results for Power Required to Drive Spindle Using 102.6 Secs. S.U.V. Oil

Spindle Speed rpm	Room Temp. ^{o}F	Oil Temp. ^{o}F	Temp. Diff. ^{o}F	Torque, in Degrees of Twist			Net Power watts
				θ_G	θ_T	θ_{net}	
---Full Bobbin---							
4000	75.5	86.5	11.0	33.0	3.5	29.5	6.1
5250	75.5	90.0	14.5	40.0	4.0	36.0	9.7
6500	76.0	93.5	17.5	48.0	4.5	43.5	14.5
7750	76.0	98.0	22.0	58.0	5.0	53.0	21.1
9000	76.5	103.0	26.5	68.5	5.5	63.0	29.2
---68% Full Bobbin---							
4000	77.0	89.0	12.0	31.0	3.5	27.5	5.6
5250	77.0	92.0	15.0	36.5	4.0	32.5	8.8
6500	76.0	93.5	17.5	43.5	4.5	39.0	13.0
7750	76.0	97.5	21.5	50.0	5.0	45.0	18.0
9000	76.0	102.0	26.0	57.5	5.5	52.0	24.1
---38.5% Full Bobbin---							
4000	76.0	87.5	11.5	27.0	3.5	23.5	4.8
5250	77.0	91.5	14.5	30.5	4.0	26.5	7.2
6500	76.0	93.5	17.5	33.5	4.5	29.0	9.7
7750	76.0	97.0	21.0	37.5	5.0	32.5	13.0
9000	76.5	100.5	24.0	41.5	5.5	36.0	16.7
---0% Full Bobbin---							
4000	77.0	88.0	11.0	25.5	3.5	22.0	4.5
5250	77.0	91.5	14.5	27.0	4.0	23.0	6.2
6500	77.0	95.0	18.0	29.0	4.5	24.5	8.2
7750	77.0	98.5	21.5	30.0	5.0	25.0	10.0
9000	77.0	102.5	25.5	32.0	5.5	26.5	12.3

APPENDIX I

TABLE IV: Test Data and Results for Power Required to Drive Spindle Using 83.5 Secs. S.U.V. Oil

Spindle Speed rpm	Room Temp. °F	Oil Temp. °F	Temp. Diff. °F	Torque, in Degrees of Twist θ_G	θ_T	θ_{net}	Net Power watts
---Full Bobbin---							
4000	75.0	85.5	10.5	30.0	3.5	26.5	5.5
5250	75.0	88.5	13.5	37.0	4.0	33.0	8.9
6500	75.0	92.5	17.5	45.5	4.5	41.0	13.7
7750	75.5	98.0	22.5	55.0	5.0	50.0	20.0
9000	76.0	102.0	26.0	66.0	5.5	60.5	28.0
---68% Full Bobbin---							
4000	76.5	86.0	9.5	27.5	3.5	24.0	4.9
5250	76.0	89.0	13.0	33.5	4.0	29.5	8.0
6500	76.0	93.5	17.5	40.0	4.5	35.5	11.9
7750	76.0	97.5	21.5	46.5	5.0	41.5	16.5
9000	76.5	100.5	24.0	54.5	5.5	49.0	22.7
---38.5% Full Bobbin---							
4000	76.5	86.5	10.0	24.5	3.5	21.5	4.4
5250	76.5	90.0	13.5	28.5	4.0	24.5	6.6
6500	76.5	95.0	18.5	32.0	4.5	27.5	9.2
7750	77.0	100.0	23.0	35.5	5.0	30.5	12.2
9000	77.0	103.0	26.0	39.0	5.5	33.5	15.5
---0% Full Bobbin---							
4000	77.0	86.5	9.5	23.0	3.5	19.5	4.0
5250	77.0	89.5	12.5	25.0	4.0	21.0	5.7
6500	77.0	94.5	16.5	26.5	4.5	22.0	7.3
7750	77.0	98.0	21.0	28.0	5.0	23.0	9.2
9000	77.0	102.0	25.0	29.5	5.5	24.0	11.1

APPENDIX I

TABLE V: Test Data and Results for Power Required to Drive Spindle Using 70.8 Secs. S.U.V. Oil

Spindle Speed rpm	Room Temp. °F	Oil Temp. °F	Temp. Diff. °F	Torque, in Degrees of Twist			Net Power watts
				θ_G	θ_T	θ_{net}	
---Full Bobbin---							
4000	77.5	86.5	11.0	29.5	3.5	26.0	5.3
5250	76.0	90.0	14.5	36.5	4.0	32.5	8.7
6500	76.0	93.5	17.5	44.5	4.5	40.0	13.4
7750	76.0	98.0	22.0	55.0	5.0	50.0	19.9
9000	76.5	103.0	26.5	65.5	5.5	60.0	27.8
---68% Full Bobbin---							
4000	77.0	89.0	12.0	26.5	3.5	23.0	4.7
5250	77.0	92.0	15.0	32.5	4.0	28.0	7.6
6500	76.0	93.5	17.5	39.0	4.5	34.5	11.5
7750	76.0	97.5	21.5	45.5	5.0	40.5	16.1
9000	76.0	102.0	26.0	54.0	5.5	48.5	22.5
---38.5% Full Bobbin---							
4000	76.0	87.5	11.5	24.0	3.5	20.5	4.2
5250	77.0	91.5	14.5	26.5	4.0	22.5	6.1
6500	76.0	93.5	17.5	30.0	4.5	25.5	8.6
7750	76.0	97.0	21.0	34.5	5.0	29.5	11.8
9000	76.5	100.5	24.0	38.0	5.5	32.5	15.1
---0% Full Bobbin---							
4000	77.0	88.0	11.0	22.0	3.5	18.5	3.8
5250	77.0	91.5	14.0	23.5	4.0	19.5	5.3
6500	77.0	95.0	18.0	24.5	4.5	20.0	6.7
7750	77.0	98.5	21.5	26.0	5.0	21.0	8.4
9000	77.0	102.5	25.5	28.0	5.5	22.5	10.5

APPENDIX I

TABLE VI: TORQUE REQUIRED TO DRIVE TENSION PULLEY AND BELT

Belt tension 1 pound
Speed ratio of spindle to tension pulley 2.75/1.25

Tension Pulley Speed rpm	Equivalent Spindle Speed rpm	Torque θ_T, in degrees twist, of torsion wire		
		Test 1	Test 2	Ave.
1600	3520	3.50	3.50	3.50
1810	3980	3.75	3.75	3.75
2390	5260	4.00	4.00	4.00
2940	6470	4.25	4.50	4.37
3520	7750	4.75	4.75	4.75
4080	9000	5.75	5.75	5.75
4540	10000	6.00	6.00	6.00
5000	11000	6.50	6.50	6.50

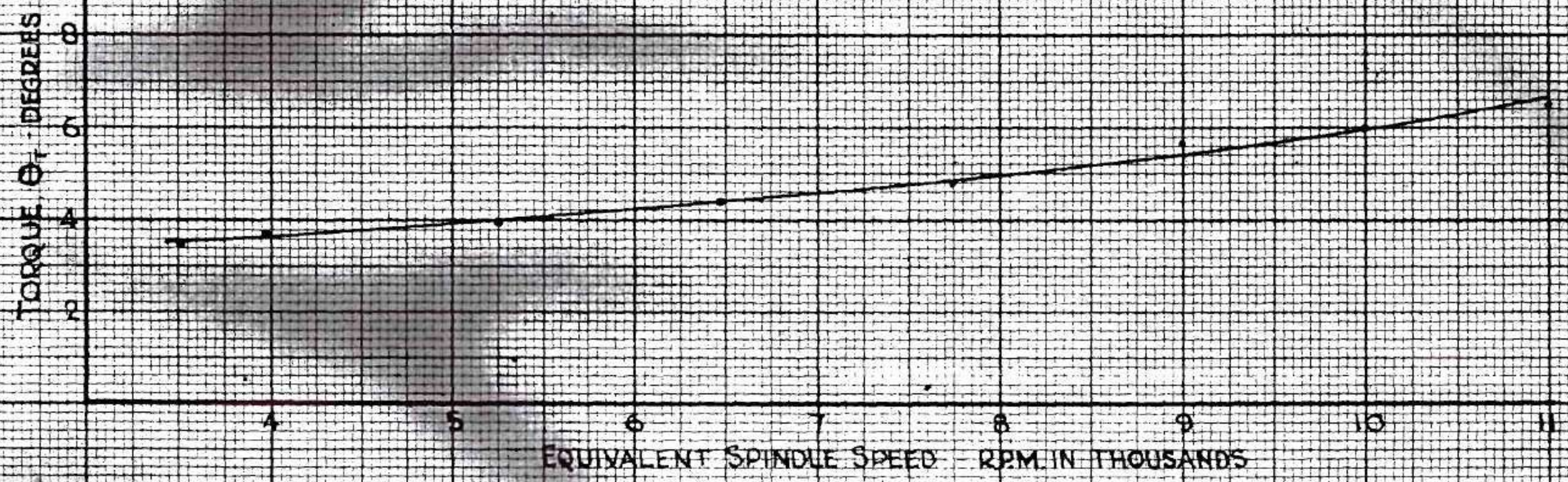


FIGURE 13
TORQUE REQUIRED TO DRIVE TENSION
PULLEY AND BELT
REF. TABLE VI

APPENDIX I

TABLE VII: CALIBRATION OF TORSION WIRE

Torque Arm 0.295 inches

Force grams	Angle of Twist θ_T		
	up	down	Ave. θ_T
175	14.5	15.0	14.7
225	19.0	19.0	19.0
275	23.0	23.0	23.0
325	27.0	27.0	27.0
375	31.0	31.0	31.0
425	35.0	35.0	35.0
475	39.0	39.2	39.1
525	43.5	43.5	43.5
575	47.5	47.5	47.5
625	52.0	52.2	52.1
675	56.0	56.0	56.0
725	60.0	60.0	60.0
775	64.0	64.0	64.0
825	68.0	68.0	68.0
875	72.0	72.2	72.1
925	77.0	77.0	77.0
975	81.0	81.5	81.2

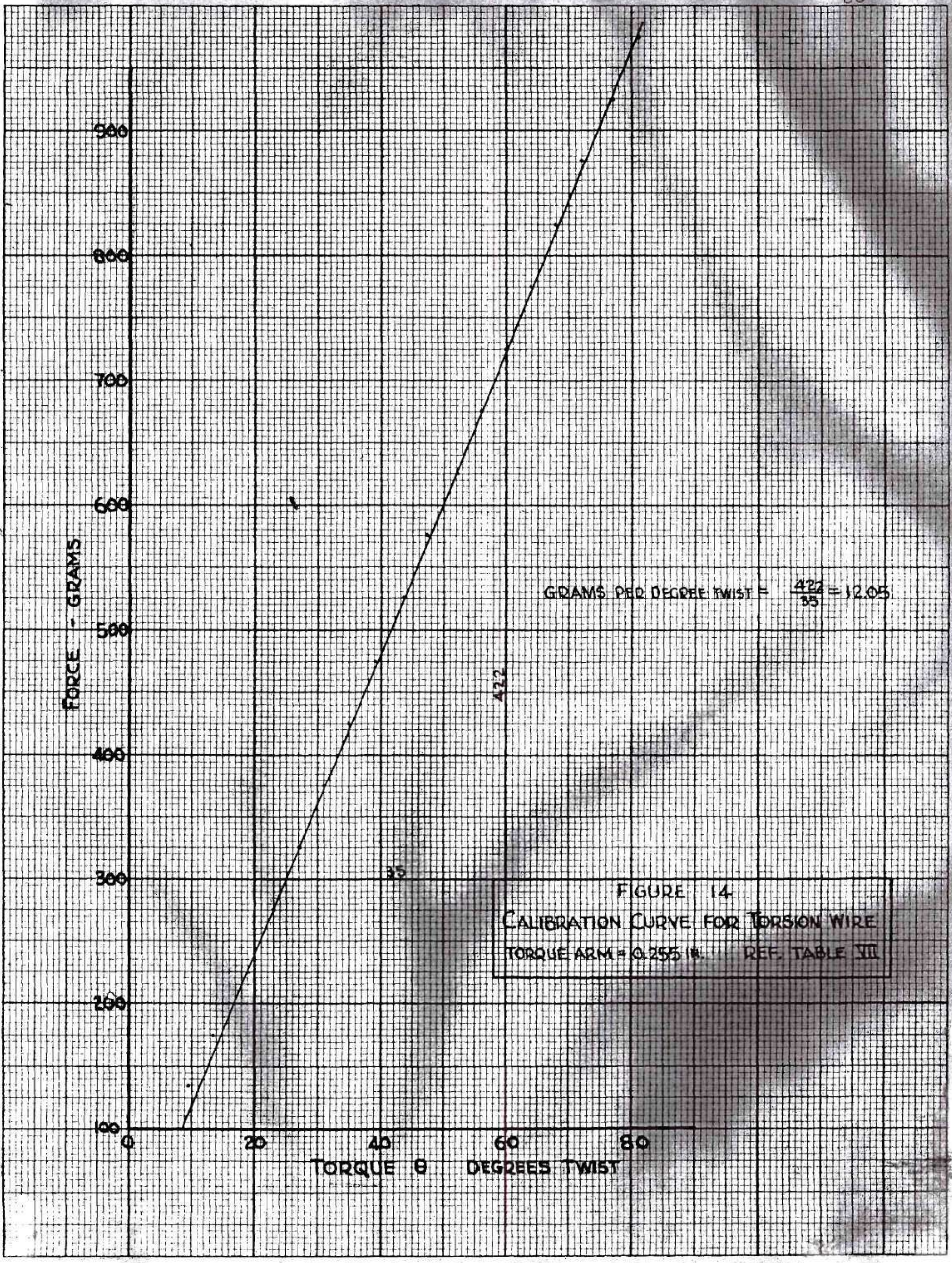


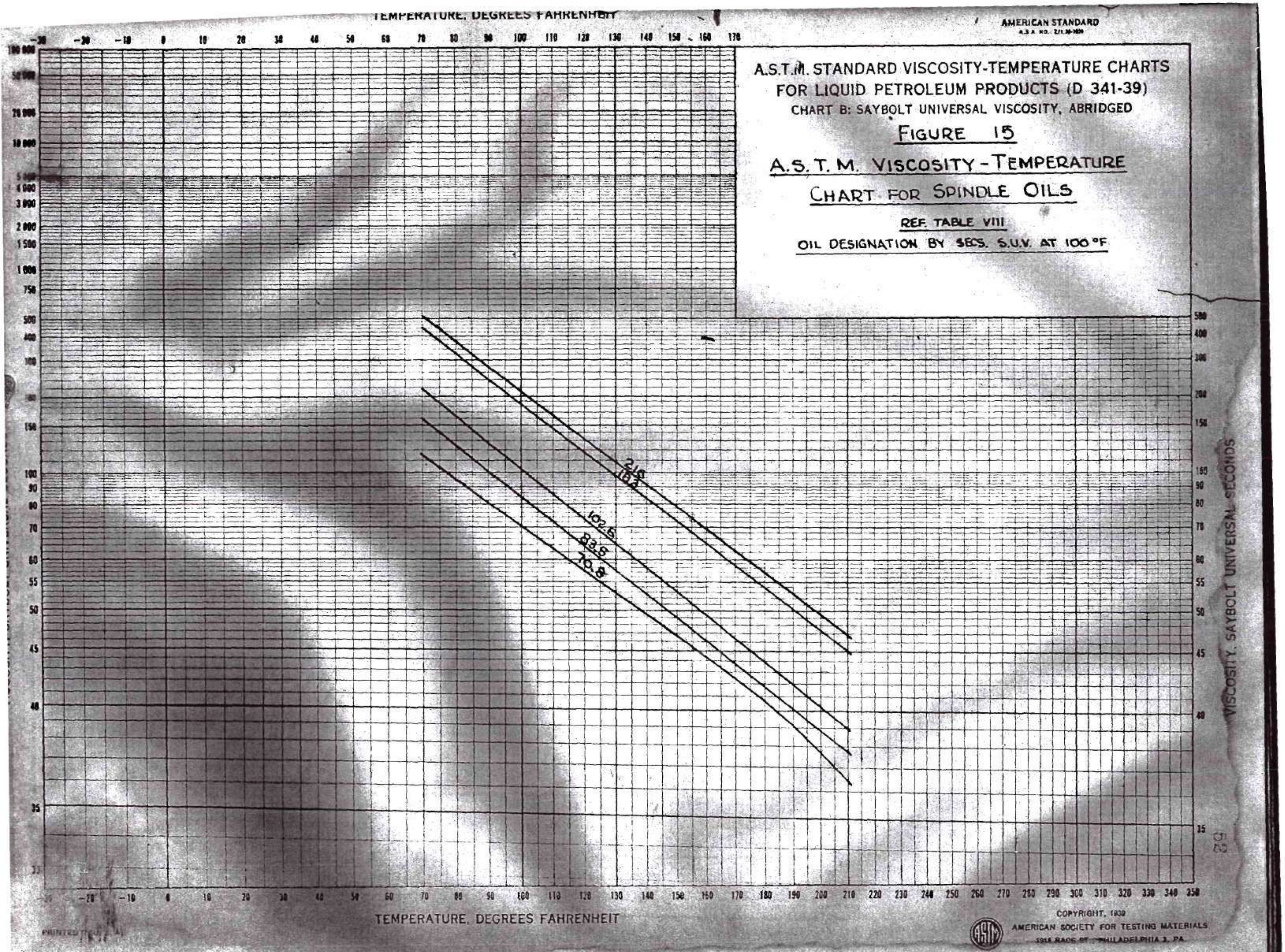
FIGURE 14
CALIBRATION CURVE FOR TORSION WIRE
TORQUE ARM = 0.255 IN. REF. TABLE VII

APPENDIX I

TABLE VIII: Physical Properties of Spindle Oils
(Courtesy of the Texas Company)

All Oils Paraffin Base

Viscosity, Secs. S.U.V. at 100°F	216.0	183.0	102.6	83.5	70.8
Viscosity, Secs, S.U.V. at 130°F	109.6	97.0	64.6	57.6	53.2
Viscosity, Secs, S.U.V. at 210°F	46.7	44.9	39.0	37.8	36.3
Gravity, °API	27.8	29.2	29.3	32.3	30.6
Flash, O-Cleve °F	410	420	380	380	335
Flash, Cleve °F	470	470	425	420	375
Color, Lovibond, 6 in. Cell	70	10	30	30	30
A.S.T.M. Pour, °F	20	25	20	25	25
Ash, %	---	none	none	none	none
TL-No.	1514	1517	1513	1515	1512


AMERICAN STANDARD
A.S.T.M. STANDARD VISCOSITY-TEMPERATURE CHARTS
FOR LIQUID PETROLEUM PRODUCTS (D 341-39)
CHART B: SAYBOLT UNIVERSAL VISCOSITY, ABRIDGED
FIGURE 15
A.S.T.M. VISCOSITY-TEMPERATURE
CHART FOR SPINDLE OILS
REF. TABLE VIII
OIL DESIGNATION BY SECS. S.U.V. AT 100 °F
TEMPERATURE, DEGREES FAHRENHEIT
VISCOSITY, SAYBOLT UNIVERSAL SECONDS
216
163
102.5
83.5
70.8
COPYRIGHT, 1939
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PHILADELPHIA 3, PA.

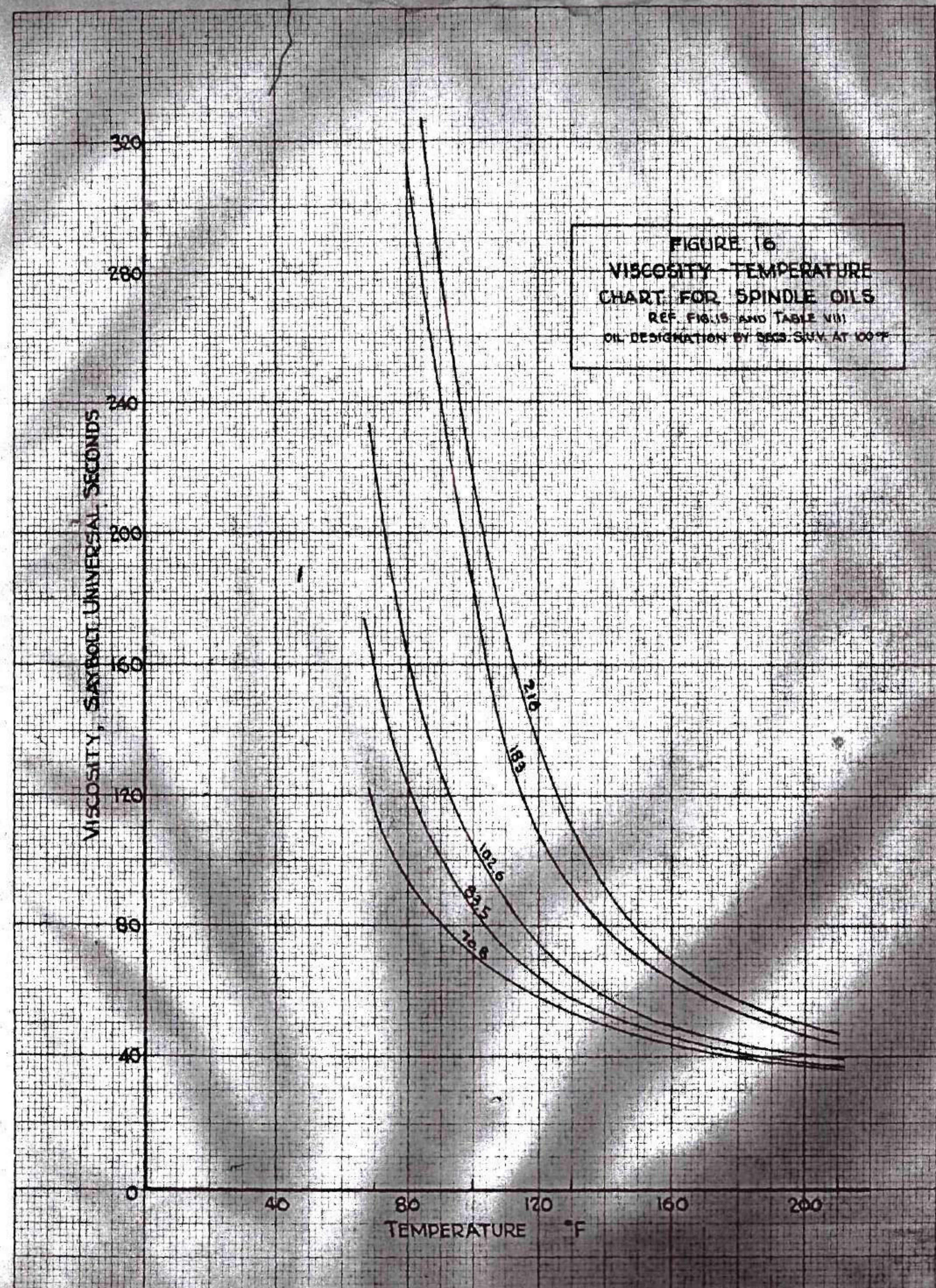
FIGURE 16
VISCOSITY - TEMPERATURE
CHART FOR SPINDLE OILS
REF. FIG. 15 AND TABLE VIII
OIL DESIGNATION BY SECS. S.U.V. AT 100°F
VISCOSITY, SAYBOLT UNIVERSAL SECONDS
TEMPERATURE °F
0
40
80
120
160
200
240
280
320
216
183
102.6
83.5
70.8

APPENDIX II

APPENDIX II

SAMPLE CALCULATIONS

Calibration of Torsion Wire:

For a description of the method used to calibrate the torsion wire, see the procedure page 15. From Fig. 14 the average number of grams per degree of twist of the torsion wire was 12.05. The torque arm used in this calibration was 0.295 inches. With this and other data, it was possible to determine a value of the torsional modulus of elasticity from the formula for torsion of a circular shaft:

$$G = \frac{T\ L}{\Phi\ J}$$

where Φ is the angle of twist in radians, T is the torque in inch pounds, L is the length of wire in inches, J the polar moment of inertia in inches to the fourth power, and G the torsional modulus of elasticity in lbs. per sq. in. From the physical dimensions of the wire, diameter 0.035 inches and length 4 inches, and the test data above

$$G = \frac{12.05\ \theta\ 0.295}{453.6} \times \frac{180}{\theta\ \pi} \times 4 \times \frac{32}{\pi\ 0.035^4}$$

where θ is the angle of twist in degrees.

$$G = 12.17 \times 10^6.$$

Power Equation:

The horsepower measured by the torsion meter may be calculated as follows:

$$\text{horsepower} = \frac{T\ n}{63000}$$ where n is speed of the motor

substituting from the torsion formula, converting to watts, and using the ratio of motor speed n to spindle speed N as $n = 1\frac{1}{4}/2\frac{1}{4}\ N = N/1.8$, we get

$$\text{Watts} = G \times \frac{\theta\pi}{180} \times \frac{\pi d^4}{32} \times \frac{1}{L} \times \frac{N}{1.8} \times \frac{1}{63000} \times 746$$

$$\text{Watts} = 5.15 \times 10^{-5}\ \theta\ N.$$

A net value of θ was determined by subtracting from the gross angle of twist the twist which was obtained by driving only the tension pulley. This net value of θ when substituted in the above equation determined the power required to drive the spindle. The equation then becomes

$$\text{Net Power, watts} = 5.15 \times 10^{-5}\ \theta_{net}\ N.$$